

## SECTION 2.0 TECHNOLOGY BACKGROUND AND STATUS

### 2.1 PROBLEM DESCRIPTION

Chlorinated solvents have been used extensively in the past by industry and government for a variety of operations, such as degreasing, maintenance, and dry cleaning. Leaks, spills, and historical disposal practices have led to widespread contamination of the soil and groundwater. Ten of the twenty-five most common groundwater contaminants at hazardous waste sites are chlorinated solvents, with TCE being the most prevalent (National Research Council, 1994).

Most chlorinated solvents belong to a class of compounds which, when present in sufficient quantity, may form dense, nonaqueous-phase liquids (DNAPLs). DNAPLs are denser than water and therefore move downward in the subsurface until they encounter a low-permeability zone or aquitard. On their way down, DNAPLs typically leave a trail of free-phase residual DNAPL that is virtually immobile and resistant to pumping. The DNAPLs present in pools or in residually saturated zones provide a long-term source for contaminant release into the groundwater, often resulting in large dissolved-phase plumes. Although most chlorinated solvents are sparingly soluble in water, their solubilities are several times higher than the U.S. EPA's maximum contaminant level (MCL) standards for drinking water. Table 2-1 shows the properties of common chlorinated solvents. Because of their low solubilities and mass transfer limitations, chlorinated solvent source zones persist in the aquifer for several years, decades, or centuries. The dissolved contaminant plume resulting from the source zone persists for similar lengths of time and has been known to travel large distances because chlorinated solvents are relatively recalcitrant to biodegradation processes at many sites.

**Table 2-1. Properties of Common Chlorinated Organic Compounds**

<b>Compound</b>	<b>MCL (mg/L)</b>	<b>Water Solubility (mg/L at 25°C)</b>	<b>Density (g/cm<sup>3</sup> at 20°C)</b>	<b>Vapor Pressure (Pascals at 25°C)</b>
Carbon tetrachloride	0.005	800	1.59	15,097
1,2-dichloroethane	0.005	8,600	1.26	9,000
Methylene chloride	0.005	20,000	1.33	46,522 (20°C)
Perchloroethylene	0.005	150	1.63	2,415
1,1,1-trichloroethane	0.2	1,250	1.34	13,300
Trichlorethylene	0.005	1,100	1.46	9,910
<i>cis</i> -1,2-dichloroethene	0.07	3,500	1.28	26,700
<i>trans</i> -1,2-dichloroethene	0.1	6,300	1.26	45,300
Vinyl chloride	0.002	2,000	0.91	350,000

Although one apparent approach would be to remediate the DNAPL source zone, in practice this often proves difficult. First, DNAPL source zones are difficult to find; when found, they are generally difficult to remediate. Therefore, at many sites, a more viable option is to treat the plume. Conventional pump-and-treat systems could be used to capture and treat the plume. However, past experience at contaminated groundwater sites and recent studies (National Research Council, 1994) have shown the inadequacies of this approach. Also, pump-and-treat systems would have to be operated for many years or decades or as long as the source zone and plume persist. The associated operational costs over several decades can be enormous. The recent development of permeable reactive barriers has presented a potentially viable alternative to conventional pump-and-treat systems.

2.2 TECHNOLOGY DESCRIPTION

Figure 2-1 shows some possible configurations of permeable barrier systems. In its simplest form, a permeable barrier consists of a zone of reactive material, such as granular iron, installed in the path of a dissolved chlorinated solvent plume (Figure 2-1a). As the groundwater flows through this permeable barrier, the chlorinated organics come in contact with the reactive medium and are degraded to potentially nontoxic dehalogenated organic compounds and inorganic chloride. The main advantage of this system is that, generally, no pumping or above-ground treatment is required; the barrier acts passively after installation. Because there are no aboveground installed structures, the affected property can

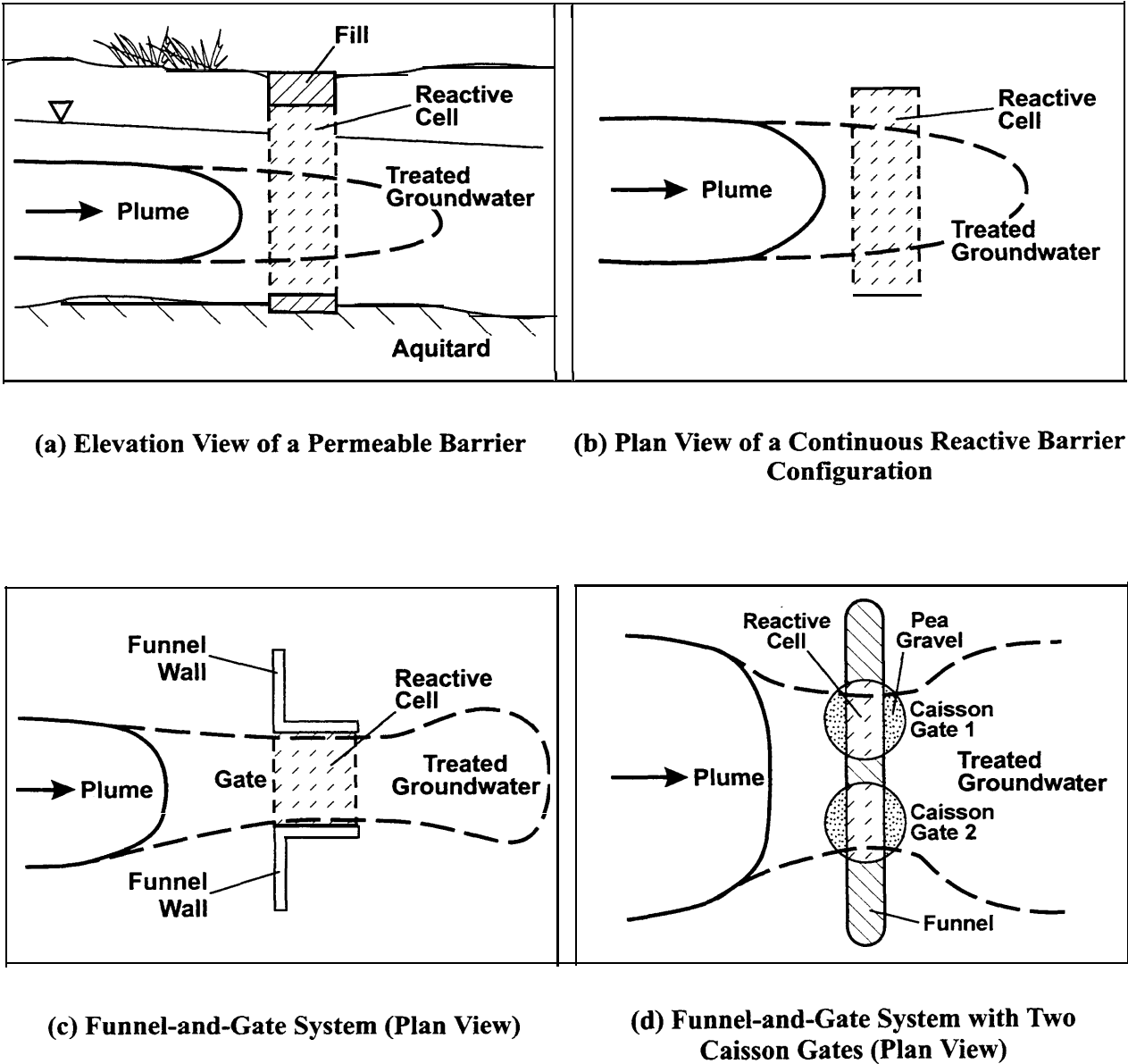


Figure 2-1. Schematic Illustrations of Some Permeable Barrier Configurations

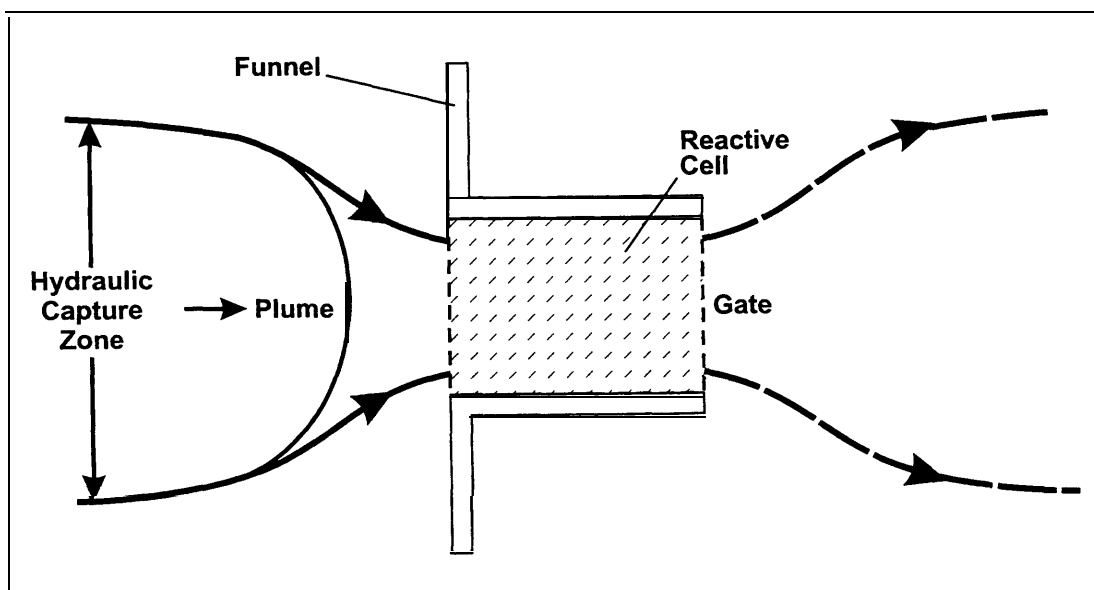
be put to productive use while it is being cleaned up. Initial evidence indicates that the reactive medium is used up very slowly and, therefore, permeable reactive barriers have the potential to passively treat the plume over several years or decades. This would result in hardly any annual operating costs, other than site monitoring. Depending on the longevity of the reactive medium, the barrier may have to be rejuvenated or replaced periodically; however, it is expected that this maintenance would be required relatively infrequently, if at all.

A permeable barrier may be installed as a continuous reactive barrier or as a funnel-and-gate system. A continuous reactive barrier (2-1b) consists of a reactive cell containing the permeable reactive medium. A funnel-and-gate system (2-1c) has an impermeable section (or funnel) that directs the captured groundwater flow towards the permeable section (or gate). This configuration sometimes allows better control over reactive cell placement and plume capture. At sites where the groundwater flow is very heterogeneous, a funnel-and-gate system can allow the reactive cell to be placed in the more permeable portions of the aquifer. At sites where the contaminant distribution is very nonuniform, a funnel-and-gate system can better homogenize the concentrations of contaminants entering the reactive cell. A system with multiple gates (Figure 2-1d) can also be used to ensure sufficient residence time at sites with a relatively wide plume and high groundwater velocity, especially when the size of each reactive cell or gate is limited by the method of emplacement (e.g., emplacement with caissons). Hydraulic modeling conducted by Starr and Cherry (1994) has shown that the most efficient funnel-and-gate arrangement is with the funnel walls aligned in a straight line with the gate (Figure 2-2a). However, other funnel-and-gate arrangements (Figure 2-2b) are possible and have been employed during previous applications. Property boundaries and geotechnical considerations (e.g., presence of underground utilities) may sometimes govern the shape of the funnel.

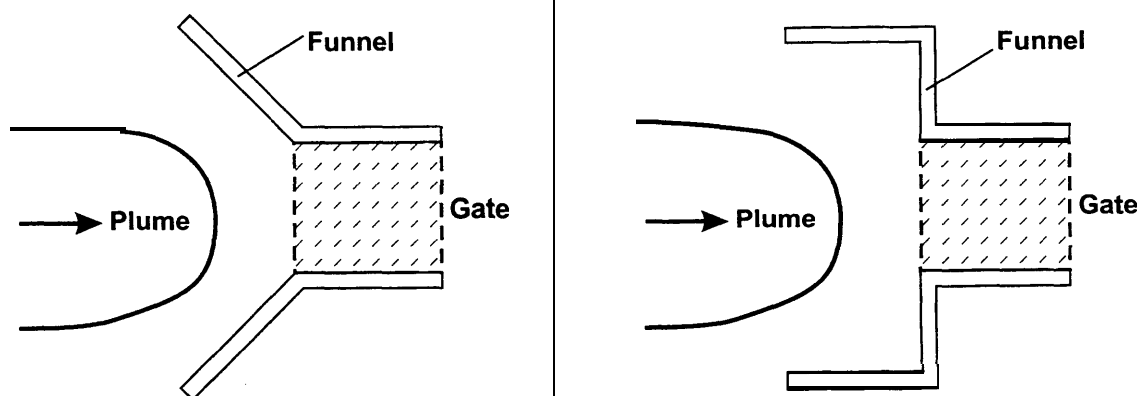
## **2.3 MECHANISM OF ENHANCED ABIOTIC DEGRADATION WITH METALS**

Although a variety of reactive media (see Section 4) could be used to treat groundwater contaminants, the most commonly used media are zero-valent metals, particularly granular iron. As the zero-valent metal in the reactive cell corrodes, the resulting electron activity is believed to reduce the chlorinated compounds to potentially nontoxic products. Because granular iron is the only reactive medium that has been used so far in field applications and because the mechanism of chlorinated solvent degradation with zero-valent iron has been the most widely studied and reported to date, most of the discussion on abiotic destruction in this document focuses on the use of granular iron as the reactive medium. Other zero-valent metals may exhibit similar reactions with differing rates.

The first reported use of the degradation potential of metals for treating chlorinated organic compounds in the environment was by Sweeny and Fischer (1972), who acquired a patent for the degradation of chlorinated pesticides by metallic zinc under acidic conditions. These researchers found that *p,p'*-DDT was degraded by zinc at ambient temperatures at a satisfactory rate with ethane as the major product. In two later papers, Sweeny (1981a and b) described how catalytically active powders of iron, zinc, or aluminum could be used to destroy a variety of contaminants, including TCE, PCE, trichloroethane (TCA), trihalomethanes, chlorobenzene, polychlorinated biphenyls (PCBs), and chlordane. The process could be carried out by trickling wastewater through a bed of iron and sand to give suitable retention and flow properties, or by fluidizing a bed of iron powder with the aqueous influent. Sweeny suggested that the reduction proceeds primarily by the removal of the halogen atom and its replacement by hydrogen (Equation 2-1), although other mechanisms probably play a role. Another important reaction suggested was the replacement of a halogen by a hydroxyl group (Equation 2-2). The iron metal was also believed to be consumed by water (Equation 2-3), although this reaction proceeds much more slowly.

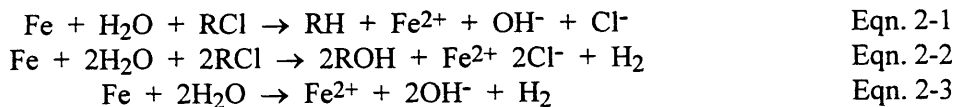


(a)



(b)

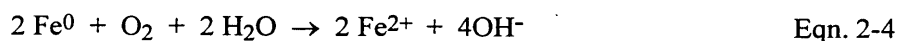
**Figure 2-2. (a) Funnel-and-Gate System with Straight Funnel. (b) Other Possible Funnel-and-Gate System Configurations**



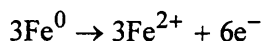
Other researchers, such as Senzaki and Kumagai (1988a, 1988b) and Senzaki (1988) also suggested the use of iron powder for removal of TCE and TCA from wastewater. However, the enormous potential of these discoveries and their in situ application was not realized until researchers at the University of Waterloo (Reynolds et al., 1990; Gillham and O'Hannesin, 1992) conducted focused

efforts in this area. The University of Waterloo currently holds the patent for the use of zero-valent metals for in situ groundwater treatment (Gillham, 1993), and has granted commercialization rights to EnviroMetal Technologies, Inc. (ETI), a company partly owned by the University.

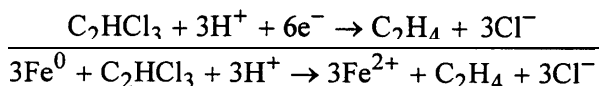
The exact mechanism of degradation of chlorinated compounds by iron or other metals is not fully understood. In all probability, a *variety of pathways* are involved, although recent research seems to indicate that certain pathways predominate. If some oxygen is present in the groundwater as it enters the reactive iron cell, the iron is oxidized and hydroxyl ions are generated (Equation 2-4). This reaction proceeds quickly, as evidenced by the fact that both the dissolved oxygen and the redox potential drop quickly as the groundwater enters the iron cell. The importance of this reaction is that oxygen can quickly corrode the first few inches of iron in the reactive cell. Under highly oxygenated conditions, the iron may precipitate out as ferric oxyhydroxide (FeOOH) or ferric hydroxide (Fe(OH)<sub>3</sub>), in which case the permeability could potentially become considerably lower in the first few inches of the reactive cell at the influent end. Therefore, the aerobicity of the groundwater can be potentially detrimental to the technology. However, contaminated groundwater at many sites is not highly oxygenated. Also, engineering controls (see Section 4.1.1.1 ) can possibly be used to reduce or eliminate oxygenation from the groundwater before it enters the reactive cell.



Once oxygen has been depleted, the reducing conditions created lead to a host of other reactions. Chlorinated organic compounds, such as TCE, are in an oxidized state because of the presence of chlorine. Iron, a strong reducing agent, reacts with the chlorinated organic compounds through electron transfers, in which ethene and chloride are the primary products (Equation 2-5).

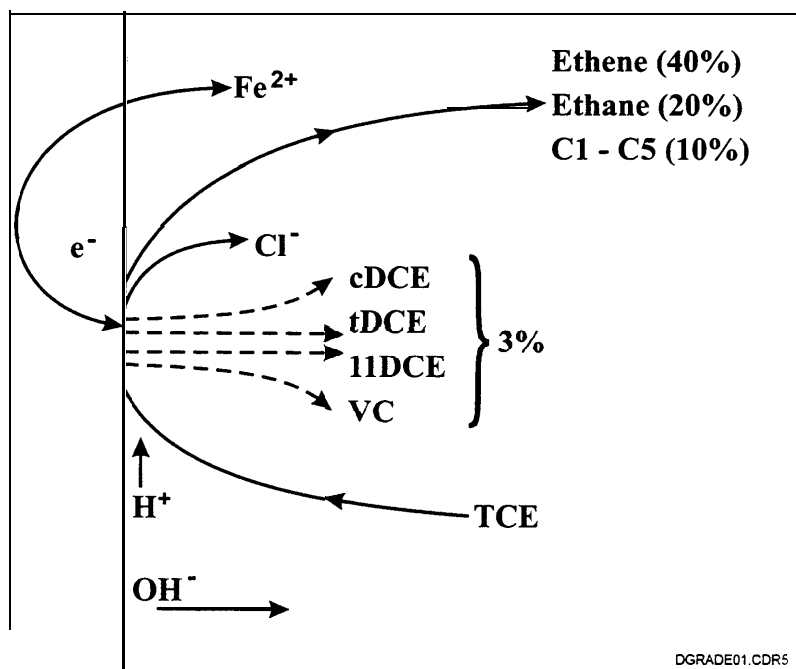


Eqn. 2-5



In one study, Orth and Gillham (1996) found that ethene and ethane (in the ratio 2:1) constitute over 80 percent of the original equivalent TCE mass. Partially dechlorinated byproducts, such as *cis*-1,2-dichloroethene (c-DCE), *trans*-1,2-dichloroethene (t-DCE), 1,1-dichloroethene, and vinyl chloride (VC) of the degradation reaction were found to constitute only 3 percent of the original TCE mass. Additional byproducts included hydrocarbons (C1 to C4) such as methane, propene, propane, 1-butene, and butane. Virtually all the chlorine in the original TCE mass was accounted for as inorganic chloride in the effluent, or as chlorine remaining on the partially dechlorinated byproducts. Similar results were obtained by Sivavec and Horney (1995), who quantified both liquid and gas phases of the reaction to obtain a carbon balance greater than 90 percent. A useful representation of the various proposed pathways is provided by Gillham (1996) and is reproduced herein Figure 2-3.

A number of interesting issues are raised by this explanation of the reaction mechanism. For Equation 2-5 to take place in one step, without the generation of larger amounts of partially dechlorinated products (e.g., DCE or VC), six electrons have to be transferred almost instantaneously. Given the low probability of an instantaneous transfer of this magnitude, Orth and Gillham (1996) suggest that the TCE molecule must remain attached to the metal surface long enough for the six-electron transfer to occur. The TCE molecule remains attached to the metal surface either through the inherent hydrophobicity of



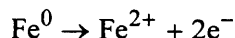
**Figure 2-3. Schematic of Proposed Degradation Process for TCE (Source: Gillham, 1996)**

TCE or, as Sivavec and Horney (1995) suggest, by the formation of a strong chloroethene-iron pi bond. This bonding prevents desorption until dechlorination is complete, although a few random chloroethene molecules may desorb early, leading to the presence of small amounts of DCE and VC. All this suggests that degradation of chlorinated organics by metals is a surface phenomenon and that the rate is governed by the specific surface area of the reactive medium.

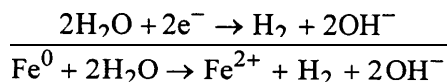
Equation 2-5 shows the transformation of TCE to ethene, which is the primary product in many studies. It is unclear whether the other significant product, ethane, represents a different degradation pathway for TCE or whether it results from the iron-mediated catalytic transformation of ethene. Also unclear is whether the C1 to C5 hydrocarbons represent an alternative pathway for TCE degradation or some other reaction. One study (Hardy and Gillham, 1996) suggests that aqueous  $\text{CO}_2$  is reduced on the iron surface to form these hydrocarbon chains. Another study (Deng et al., 1996) suggests that the source of these hydrocarbons is the acid dissolution of gray cast irons containing both carbide and graphite carbon.

There is some indication that PCE and TCE in contact with iron may, at least partly, degrade through a different pathway from the one discussed above. Roberts et al. (1996) have seen some indication from their experiments that PCE and TCE could be reduced to dichloroacetylene and chloroacetylene, respectively. Both of these byproducts are potentially toxic, but are likely to be short-lived. Hydrogenolysis could lead to their transformation to lesser chlorinated acetylenes, which could further be reduced to substituted ethylenes. Hydrolysis of the chloroacetylenes to acetates is also a possible pathway. In summary, there may be multiple pathways by which chlorinated ethylenes, such as PCE and TCE, are transformed in the presence of iron into dehalogenated products such as ethene.

Iron also reacts with *water* under reducing (anaerobic) conditions, although this reaction is believed to be much slower. The slow reaction with water (Equation 2-6) is advantageous to the technology because very little reactive medium (iron) is used up in this side reaction. Hydrogen gas and OH<sup>-</sup> are formed as water is reduced, as shown in Equation 2-6.



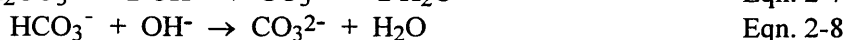
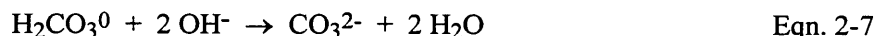
Eqn. 2 - 6



Hydrogen generation could be a concern if hydrogen accumulates in the aquifer as it appears to do in some column tests. However, although initial field users were prepared to install hydrogen-gas collection systems, this has not been necessary at any site so far. Hydrogen generated by the slow reaction is believed to degrade through biological transformations (ETI, 1996).

Because several of the above reactions produce OH<sup>-</sup>, the pH of the water in the reactive iron cell typically increases, often reaching values above 9.0. One effect of increased pH initially was thought to be a slowing down of the TCE degradation rate (O'Hannesin, 1993). The anticipation was that changes in pH might cause changes in the degradation rate through direct involvement of H<sup>+</sup> in Equation 2-5. However, subsequent research raised questions about whether or not pH affects degradation rate (Agrawal and Tratnyek, 1996).

An indirect effect of increasing pH is the potential for formation of precipitates, which could coat the surface of the iron and potentially reduce the reactivity of the iron and the hydraulic conductivity of the reactive cell. The dissolved carbonic acid and bicarbonate (alkalinity) present in many natural groundwaters act as buffers limiting pH increase and precipitate formation (Equations 2-7 and 2-8).



Soluble carbonate ions are formed as the OH<sup>-</sup> ions are consumed. If carbonate ions continue to build up, however, precipitation of carbonate solid species may occur. Depending on the composition of the groundwater, the precipitates formed could be calcite (CaCO<sub>3</sub>), siderite (FeCO<sub>3</sub>), or magnesium hydrocarbonates (Reardon, 1995). If groundwater carbonate is exhausted through the precipitation of carbonate minerals, the water may become saturated with respect to Fe(OH)<sub>2</sub> as the iron continues to oxidize. Fe(OH)<sub>2</sub> is relatively insoluble and may precipitate out if it builds up.

In summary, most groundwaters contain many different aqueous species that may play some role in affecting the performance of a permeable barrier. In general, the course of chemical reactions taking place in multicomponent systems cannot be predicted by considering each species individually, because most of these reactions are interdependent. To some extent, equilibrium behavior in complex systems can be predicted using geochemical modeling codes, which are described in Section 6.2. However, many groundwater reactions in permeable barrier systems may not reach equilibrium during the passage of groundwater through the reactive cell. Another difficulty is that even if the type and mass of reaction products could be predicted, it is uncertain as to how many of these products are actually retained in the reactive cell and affect performance. For example, very fine precipitates that may be formed could be carried out of the reactive cell by colloidal transport with the groundwater flow. However, the reaction

chemistry discussed above and the geochemical modeling codes described in Section 6.2 do provide a basis for selecting appropriate reactive media and planning performance monitoring schemes after permeable barrier installation.

## **2.4 POTENTIAL BIOLOGICALLY MEDIATED REACTIONS IN THE REACTIVE CELL**

Gillham and O'Hannesin (1994) conducted column tests on TCE-contaminated water, both with and without an added biocide (azide). Similar degradation rates were observed in both cases demonstrating that the degradation of TCE was abiotic and could proceed without microbial intervention. Also, microbial analysis (phospholipid fatty acid measurements) of the groundwater conducted during a pilot study at an industrial facility in Sunnyvale, California indicated no signs that the reactive media encouraged development of a microbial population over that in the surrounding aquifer (ETI, 1995).

However, the potential for microbially mediated processes in the reactive cell may be present under certain conditions. No significantly enhanced microbial activity has been noticed in the reactive cell at field installations to date (ETI, 1997). Appendix A-3 describes some possible biologically mediated reactions that have been proposed given the geochemistry of groundwater and the presence of iron.

## **2.5 CURRENT STATUS OF PERMEABLE BARRIER FIELD APPLICATIONS**

Table 2-2 describes the current status of pilot- and full-scale field applications of this technology at various sites. Granular iron was used as the reactive medium in all these field applications. The reactive medium was emplaced either in an excavated trench or a caisson driven into the ground. Installations were configured either as continuous reactive barriers or as funnel-and-gate systems. Funnel walls were either sealable-joint sheet piling or slurry walls. Trench-type reactive cells have been placed at depths down to 30 feet maximum. Caisson-type reactive cells have been placed at depths down to 40 feet maximum. At the present time, depth is the greatest limitation for field application of this technology. Additional information on selected sites is provided in Appendix E.

## **2.6 EFFORTS OF GOVERNMENT AGENCIES TO PROVIDE REGULATORY GUIDANCE FOR THE USE OF PERMEABLE BARRIERS**

In an effort to promote more regular consideration of newer, less costly, and more effective technologies to address the problems associated with hazardous waste sites, the U.S. EPA has published six In Situ Remediation Technology Status Reports, one of which deals with permeable barriers (U.S. EPA, 1995). This document briefly describes demonstrations, field applications, and research on permeable barriers. There is a growing interest in this technology at the state level as well.

The ITRC work group is a group striving to build a consensus on regulatory issues surrounding various remedial technologies. The ITRC has formed a Permeable Barriers Subgroup. This Subgroup first convened at a meeting in Philadelphia on September 25, 1996. The Permeable Barriers Subgroup includes members from environmental regulatory agencies in 29 states, as well as other interested parties such as environmental groups, the U.S. military, industry, and environmental consulting firms. The Subgroup will attempt to develop a consensus document for the states that will enhance the regulatory acceptance of this new technology and provide a consensus on requirements for compliance monitoring. Although a general regulatory consensus on permeable barriers will be announced by the Subgroup, individual states may decide to add on their own specific requirements.

**Table 2-2. Current Status of Permeable Barrier Applications for Chlorinated Solvent Sites (Source: ETL, 1996)**

Site Name/Location	Intersil, Sunnyvale, CA	Industrial Facility, Upstate New York	Industrial Facility, Mountain View, CA	Electronics Facility, Belfast, N. Ireland	Industrial Facility, Coffeyville, Kansas
Pilot/Full Scale	Full	Pilot	Full	Full	Full
Date Installed	12/94-1/95	5/95	9/95	12/95	1/96
Type of Barrier	Iron gate with slurry wall funnels	Iron gate with sheet pile (funnels 15 ft either side)	Continuous iron cell	In situ caisson reactor with slurry walls (80-100 ft on either side)	Iron cell with slurry walls (500 ft on either side)
Depth of Barrier	20 ft	15 ft	25 ft	40 ft	28 - 30 ft
Type of Media	iron	iron	iron	iron	iron
Total (and Unit) Cost of Media	\$170,000 (\$650/ton)	\$30,000 (\$650/ton)	\$60,000 (\$650/ton)	\$20,000 (\$450/ton)	\$50,000 (\$650/ton)
Contaminants and Concentrations	TCE, cDCE, VC, freon-113	TCE 30-380 ppb VC 4.9-7.1 ppb cDCE 98-550 ppb 1,1,1-TCA 3.2-13 ppb	cDCE 5-10 ppm VC 5-50 ppb TCE up to/1 ppm	TCE 300,000 ppb 1,1,2-TCA 200 ppb cDCE 2000 ppb Trace others ppb	TCE 400 ppb
Emplacement Technique Used for Funnel-and-Gate Portions	Gate - Trench box Funnel - slurry walls	Gate - Trench box Funnel - Sealable sheet pile	Backhoe, emplaced during backfilling of open pit.	Cylindrical reactive vessel filled with iron, slurry walls	Soil-bentonite slurry walls
Installation Cost (all U.S. dollars)	\$600,000	\$220,000	Completed as part of overall site remediation (not a big incremental cost over backfilling)	\$315,000	\$400,000 including iron
Compliance Monitoring Well Locations	In last 4 inches of iron cell	In downgradient pea gravel	In downgradient section of iron	Various locations in cylinder	Various locations in iron cell
Comments	MODFLOW model	FLOWPATH model	No computer modeling	FLOWPATH model	FLOWPATH model

**Table 2-2. Current Status of Permeable Barrier Applications for Chlorinated Solvent Sites (Continued)**

Site Name/Location	Lowry AFB, Denver, CO	Moffett Federal Airfield, CA	USCG Facility, Elizabeth City, NC	Canadian F. B. Bordon, Canada	Denver Federal Center, CO
Pilot/Full Scale	Pilot	Pilot	Full	Pilot	Full
Date Installed	11-12/95	4/96	6/96	6/91	10/96
Type of Barrier	Funnel-and-gate, sheet pile walls	Funnel-and-gate, sheet pile walls	Continuous iron trench (150 ft)	Continuous reactive wall	Funnel-and-gate 1,000 ft long, four 40-ft gates
Depth of Barrier	18 ft	25 ft	24 ft	32 ft	20 ft
Type of Media	Iron	Iron	Iron	Iron and sand mixture	Iron
Total (and Unit) Cost of Media	\$32,500 (\$650/ton)	NA	±\$171,000 (\$380/ton)	NA	(\$375-400 ton)
Contaminants and Concentrations	TCE 1,000 ppb cDCE 250 ppb VC 25 ppb	TCE >20 mg/L PCE 0.5 mg/L	TCE up to 16 mg/L Cr 6-10 ppm	TCE 250,000 ug/L PCE 43,000 ug/L TCM NA	
Emplacement Technique Used for Funnel-and- Gate Portions	sealable-joint sheet pile funnel walls; trenched gate	sealable-joint sheet pile funnel walls; trenched gate	Continuous trencher	Clamshell excavated trench	Sheet pile for funnel
Installation Cost (all U.S. dollars)	\$137,500 including iron	\$380,000 including iron(?)	\$350,000 including iron.	NA	\$900,000-\$1,000,000 (final not yet known)
Compliance Monitoring Well Locations	Various locations in iron	Various locations in iron	Upgradient and downgradient	2 wells upgradient, 3 downgradient, 6 in iron	Various locations in iron and downgradient pea gravel
Comments	MODFLOW model	MODFLOW model	FLOWPATH	NA	MODFLOW model

**Table 2-2. Current Status of Permeable Barrier Applications for Chlorinated Solvent Sites (Continued)**

Site Name/Location	Industrial Facility, New Jersey	Somersworth Sanitary Landfill, NH	Alameda Naval Air Station, CA
Pilot/Full Scale	Pilot	Pilot	Pilot
Date Installed	11/94	Current (10-11/96)	11-12/96
Type of Barrier	Aboveground iron reactor	Slurry walls (10 ft), 8-ft-diameter caisson with iron	Sheet pile with sequential iron, O <sub>2</sub> sparge gate
Depth of Barrier	NA	40-45 ft	15 ft
Type of Media	Iron	Iron	Iron + O <sub>2</sub> sparge gate
Total (and Unit) Cost of Media	NA	~ \$100,000 total	Iron \$375/ton
Contaminants and Concentrations	TCE 3,000 µg/L PCE 50,000 µg/L	TCE 310 ppb PCE 3.7 ppb cDCE 565 ppm VC 387 ppb	cDCE VC BTEX 1-5mg/L
Emplacement Technique Used for Funnel-and- Gate Portions	NA	Caissons, slurry walls	Trench box
Installation Cost (all U.S. dollars)	NA	\$175,000	To be determined
Compliance Monitoring Well Locations	Side ports along reactor	Various locations in iron	Various locations in iron
Comments	NA	Visual MODFLOW, FRAC3DVS	Rice/U. of Waterloo Project Visual MODFLOW

According to the Subgroup, there currently are no specific regulatory requirements for installation or monitoring of permeable barriers (Turner, 1996). For the few systems that have been installed to date, regulatory requirements have been determined on a case-by-case basis. The California Department of Toxic Substances Control likewise makes its determinations on a case-by-case basis (Hadley, 1996). Regulatory agencies currently suggest that for a prospective site there should be (1) compelling reasons why a permeable barrier is the best choice for that site and (2) data to show why it is expected to work as planned. Different states, or even different agencies within a state, are likely to have different requirements.

Intersil, the site with the first full-scale permeable barrier application, was in many ways an ideal situation from a technical feasibility and regulatory viewpoint. It was an underutilized property, was run by a cooperative potentially responsible party (PRP), and posed no excessive human health threat. Further, it had shallow groundwater, poor (brackish) water quality, a competent aquitard, and a wall that was not too deep. A pilot study on site showed that the barrier would work and that the total cost was estimated as half that of a pump-and-treat system over 30 years (Kilfe, 1996). The cost analysis for this site assumed that the iron would not require replacement and included the benefit of being able to lease the property, an option that was enabled by the passive long-term nature of the technology. Although the plume had moved off the property at Intersil, regulators allowed placement of the permeable barrier within property lines based on indications that natural attenuation of the chlorinated contaminants was occurring downgradient.

Other sites may be more difficult from a regulatory viewpoint. At one potential site where a full-scale permeable barrier is being considered, the approval process is made difficult by the fact that there is already a Record of Decision (ROD) with 30 signatories (PRPs) in place for installing a pump-and-treat system to clean up a regional plume. There may also be problems with site access if the plume has already moved beyond the property boundary and the permeable barrier is required to be installed at the leading edge of the plume.

One important trend is that regulators are increasingly open to discussion of cleanup costs. There is a growing willingness in the regulatory community to consider cost an important factor in selecting alternatives for cleanup. If a large benefit-to-cost ratio can be shown for the permeable barrier versus a pump-and-treat system, it would be a considerable factor in favor of its selection.

For many chlorinated compounds, the degradation potential of a permeable iron barrier has been demonstrated with a fair degree of confidence by various published research. Site-specific degradation feasibility can be shown through the treatability tests described in Section 5.0. From a regulatory perspective, the questions that remain relate to ensuring hydraulic capture of the plume, maintaining long-term performance (in terms of hydraulics and reactivity), and verifying downgradient water quality. These issues can be addressed by developing a site-specific monitoring program for the permeable barrier system. It is recommended that site managers confer with regulators as early as possible in the design stage to promote better understanding of the needs of all concerned parties.